

## OBSERVATION OF A BLACK-HOLE X-RAY NOVA IN OUTBURST WITH INTEGRAL

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## ABSTRACT

We simulate the observation of a bright Nova Musca-like X-ray nova during outburst with INTEGRAL, the next ESA  $\gamma$ -ray space observatory. We will show how performances of the INTEGRAL instruments allow deep study of X-ray Novae and will evaluate the scientific output that INTEGRAL will provide on this class of transient gamma-ray sources, which are now believed to contain black holes in low mass binary systems.

The variable high-energy feature around 511 keV observed from X-ray Nova Musca in 1991 by the SIGMA telescope would be detected by INTEGRAL at very high significance level. INTEGRAL data will permit to set important constraints on the models and allow to distinguish between electron-positron or nuclear de-excitation origin of the line. Characteristic spectral and timing features detected by INTEGRAL instruments over a very large energy band will also provide clues to understand physics of accretion in these black holes binaries and in particular to distinguish between thermal and non-thermal origin of radiation and to assess the role of bulk motion comptonization.

Key words: X-ray Nova; spectroscopy; simulations.

## 1. INTRODUCTION

X-ray Novae are a class of transient sources which sparked considerable interest in recent years because most of them are believed to host black holes (Tanaka & Shibazaki 1996). In particular bright X-ray Novae can become the brightest objects in the X-ray sky with fluxes of the order of 1 Crab or even much more like in the case of A0620-00 which had a maximum flux of several Crab units (Elvis et al. 1975). X-ray Novae have been discovered and observed in the standard 1-10 keV X-ray band during the last 30 years (see e.g. Chen et al. 1997). In the last decade observations with CGRO and SIGMA have started to record X-ray Novae outbursts also in the hard X-ray ( $> 50$  keV) band (see e.g. Paciesas et al. 1995, Goldoni 1999).

X-ray Novae are most probably LMXB in which accretion is not normally operating during their quiescent period. Material from the companion accumulates in a low viscosity disc which increases in mass and temperature until thermal and viscous instabilities due to increased opacity of disc plasma produce a sudden fall of matter in the potential well and an outburst in X-rays (Cannizzo 1993).

The typical 1-10 keV X-ray spectrum is rather soft characterised by a black body component with  $kT \leq 1$  keV similar to the one observed in persistent LMXB. Hard X-ray emission on the other hand may extend up to several hundreds of keV: up to energies of about 100 keV it has been modeled as thermal comptonisation from an extended corona (Sunyaev & Titarchuk 1980). At higher energies different mechanisms are required like bulk motion from free falling electrons (Laurent & Titarchuk 1999), or alternatively synchrotron emission from a population of non thermal particles in the corona or possibly in a jet (Gierlinski et al. 1999). The origin of high energy ( $> 50$  keV) radiation in X-ray Novae and in general in accreting relativistic objects is one of the most important open problems in this field.

One of the most important features of the hard X-ray emission of X-ray Novae is the variable 511 keV feature observed with SIGMA on 1991 January 20 in X-Nova Muscae 1991 (Goldwurm et al. 1992, Sunyaev et al. 1992). This transient feature was centered at  $\sim 480$  keV, close to pair annihilation energy, its width was compatible with the broad instrument resolution ( $< 60$  keV) and its flux was  $\sim 6 \times 10^{-3} \text{ cm}^{-2} \text{ s}^{-1}$ . It was detected only during the last 13 hours of a 21 hours observation and it was visible at a  $5.1 \sigma$  level in images in the 430-530 keV band. The images of the observing session in different energy bands are shown in Figure 1 while the total spectrum is shown in Figure 2. The 40-1000 keV continuum spectrum was fitted with a power law with photon index  $\alpha = 2.38$  and flux  $F = 6.8 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ .

This phenomenon has been first linked to gravitationally redshifted  $e^+e^-$  annihilation in the vicinity of the accreting object (Goldwurm et al. 1992, Sunyaev et al. 1992). Another interpretation (Martin et al. 1996) is excited  ${}^7\text{Li}$  decay, which produces a line centered at 476 keV. A better understanding of this

phenomenon could without doubts give very important clues on the accretion phenomenon and on the surrounding environment. New observations of this transient line are therefore needed. INTEGRAL will be perfectly suited for this task thanks to its wide band coverage and to its exceptional sensitivity in the hard X-ray band coupled with soft X-ray monitoring. In fact several other phenomena like QPOs, Compton reflection on the disk, iron fluorescent lines are present in these sources in the soft and hard X-ray bands. The interrelation between these phenomena are often complicated, in order to model them in a satisfactory way a complete spectral coverage of the source's emission is required.

In the following we present simulations of an IBIS observations of a bright X-ray Nova displaying a transient Nova Musca-like feature during a 13 hours outburst.

## 2. THE INTEGRAL SATELLITE AND ITS INSTRUMENTS

INTEGRAL is a 15 keV-10 MeV  $\gamma$ -ray mission with concurrent source monitoring at X-rays (3-35 keV) and in the optical range (V, 500- 600 nm). All instruments are coaligned and have a large FOV, covering simultaneously a very broad range of sources. The INTEGRAL payload consists of two main  $\gamma$ -ray instruments, the spectrometer SPI and the imager IBIS, and of two monitor instruments, the X-ray monitor JEM-X and the Optical Monitoring Camera OMC.

The Imager on Board Integral Satellite (IBIS) provides diagnostic capabilities of fine imaging (12' FWHM), source identification and spectral sensitivity to both continuum and broad lines over a broad (15 keV–10 MeV) energy range. It has a continuum sensitivity of  $2 \times 10^{-7}$  ph cm $^{-2}$  s $^{-1}$  at 1 MeV for a  $10^6$  seconds observation and a spectral resolution better than 7 % @ 100 keV and of 6 % @ 1 MeV. The imaging capabilities of IBIS are characterized by the coupling of its source discrimination capability (angular resolution 12' FWHM) with a field of view (FOV) of  $9^\circ \times 9^\circ$  fully coded and  $29^\circ \times 29^\circ$  partially coded.

The IBIS detection system is composed of two planes, an upper layer made of 16384 squared CdTe pixels (ISGRI) with higher efficiency below about 200 keV and a lower layer made of 4096 CsI scintillation bars (PICsIT) more efficient above 200 keV. A photon can interact with only one of the two layers giving rise to an ISGRI or a PICsIT event (the PICsIT event can be single or multiple). If it interacts with both, undergoing a Compton scattering, its energy and arrival direction can be reconstructed leading to the definition of a third type of event, the Compton one which again can be single or multiple depending on interaction in PICsIT.

The spectrometer SPI will perform spectral anal-

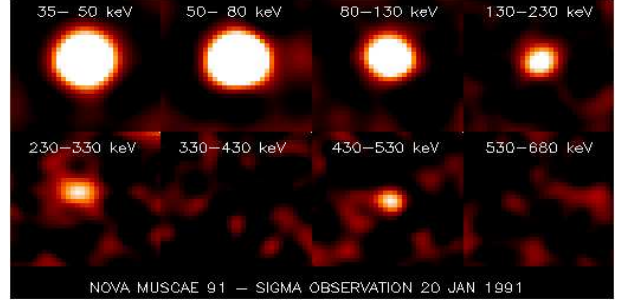


Figure 1. SIGMA images in different energy bands of X-Nova Muscae 1991 during the flare of January 20 1991. The source disappears in the 330-430 keV band and reappears in the 430-530 keV band.

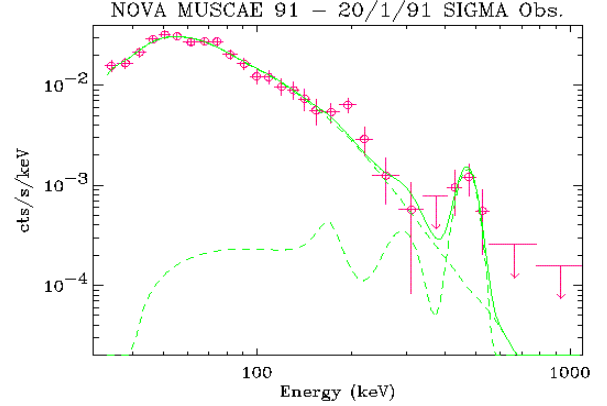


Figure 2. SIGMA spectrum of X-Nova Muscae 1991 during the flare, the feature is modeled with an electron-positron annihilation line plus a positronium continuum.

ysis of  $\gamma$  ray point sources and extended regions with an unprecedented energy resolution of  $\sim 2$  keV (FWHM) at 1.3 MeV. Its large field of view ( $16^\circ$  circular) and limited angular resolution ( $2^\circ$  FWHM) are best suited for diffuse sources imaging but it retains nonetheless the capability of imaging point sources. It has a continuum sensitivity of  $7 \times 10^{-8}$  ph cm $^{-2}$  s $^{-1}$  at 1 MeV and a line sensitivity of  $5 \times 10^{-6}$  ph cm $^{-2}$  s $^{-1}$  at 1 MeV, both  $3\sigma$  for a  $10^6$  seconds observation.

The Joint European Monitor JEM-X supplements the main INTEGRAL instruments and provides images with 3' angular resolution in a  $4.8^\circ$  fully coded FOV in the 3-35 keV energy band. The Optical Monitoring Camera (OMC) will observe the prime targets of INTEGRAL main  $\gamma$  ray instruments. Its limiting magnitude is  $M_V \sim 19.7$  ( $3\sigma$ ,  $10^3$  s). The wide band observing opportunity offered by INTEGRAL provides for the first time the opportunity of simultaneous observations over 7 orders of magnitude in energy.

Table 1. Simulation statistics, we quote simulated and detected photons in different instrument modes. The Compton mode is by far the less efficient however it can produce useful data thanks to its low expected background.

| Simulated photons | ISGRI   | Compton<br>single,multiple | PICsIT<br>single,multi |
|-------------------|---------|----------------------------|------------------------|
| 1.500.000         | 100.000 | 2500,900                   | 44700,262              |

### 3. SIMULATIONS

The INTEGRAL observing program is divided in a core program reserved to instrument teams and collaborators and an open observing program. Core program Target of Opportunity observations are foreseen soon after a bright Nova outburst is discovered. Presently the observing time envisaged is about  $8 \times 10^5$  seconds, i.e. 10 days. Given the brightness of the source and INTEGRAL sensitivity, several high quality spectra will be produced.

It is expected that total flux and spectral shape of the X-ray Nova will change during this observation. The flare we model happens when the continuum flux of the Nova has fallen to  $\sim 200$  mCrab in the 40-300 keV energy band.

Our simulations were performed using the current version (3.1) of the IBIS mass model (Laurent et al. 2000). This is a specific software project developed to build a complete geometrical model of the IBIS instrument in order to correctly evaluate the instrumental background and spectral response. The IBIS mass model simulates the geometry of IBIS using the Geant software (Brun et al. 1994) and then allows to perform Monte Carlo simulations of the interactions between photons and the telescope structure.

Taking the spectral parameters of the 20 January 1991 flare defined above, we simulated  $\sim 1.500.000$  photons in the total IBIS band from 20 to 1000 keV. We simulated the feature as a broad gaussian line at 480 keV with  $\sigma = 22$  keV. In Table 1 we summarize the main results of our simulation. We stress that we do not simulate the background at the present stage, we will make assumptions about its countrate and spectrum.

The results of our MonteCarlo simulations are shown in Figure 3, 4 and 5 and summarized in Table 1. The two layers and the Compton mode all show clearly the presence of the spectral feature. We added to these results a uniform background taken from our present estimation. We took a power law background spectrum with photon index -2 and total count rate of  $1000 \text{ c s}^{-1}$ ,  $7500 \text{ c s}^{-1}$  and  $100 \text{ c s}^{-1}$  for ISGRI, PICsIT and the Compton mode respectively. With these background values we obtain a  $20\sigma$  detection in ISGRI and PICsIT and a  $\sim 8\sigma$  detection in the Compton mode.

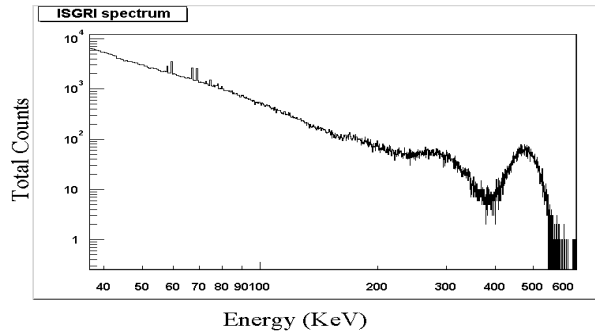


Figure 3. ISGRI simulated spectrum of the X-ray Nova flare with no background, the line and its backscattering peak are clearly visible while the lines at low energies are fluorescence lines in the telescope structure. The spectrum contains  $\sim 100.000$  photons.

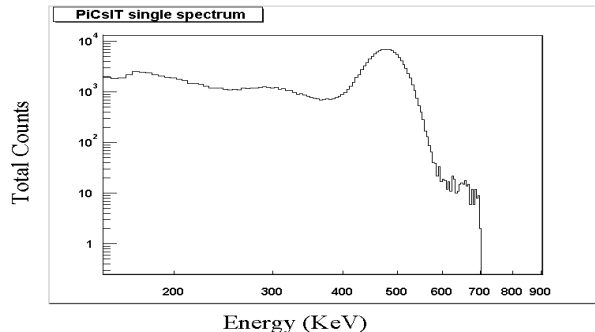


Figure 4. PICsIT total spectrum of the X-ray Nova flare with no background, it contains a total of  $\sim 67.000$  photons, half of which in the line.

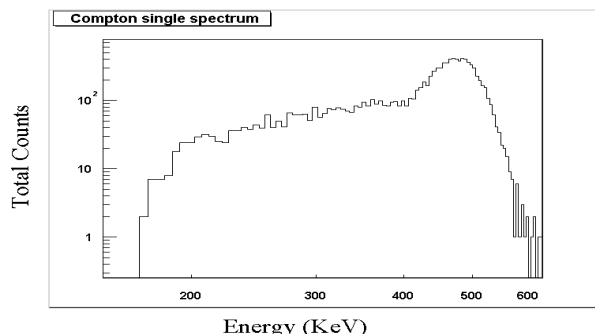


Figure 5. Compton mode total spectrum of the X-ray Nova flare with no background, it contains  $\sim 3400$  photons, half of which in the spectral line.

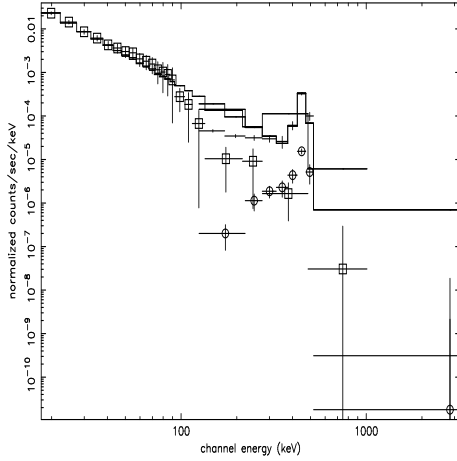


Figure 6. *ISGRI*, *PiCsIT* and *Compton* mode spectrum of the X-ray Nova during the flare, background is included (see text). *ISGRI* points are indicated by squares, *PiCsIT* points by spheres and *Compton* points by simple crosses. A model spectrum composed by a power law with photon index  $-2.4$  and a line centered at an energy of  $480$  keV with a  $22$  keV width is shown for comparison.

The final results are shown in Figure 6, for this particular scenario the line is clearly detected by the *PiCsIT* layer and by the *Compton* mode. Altogether the *IBIS* instrument provides a full coverage of the X-ray Nova flare up to  $\sim 600$  keV. At the present stage we have not produced a response matrix for the instrument, the channel-energy conversion has been performed in a preliminary way, a formal fit is therefore not possible. However the general shape of the spectrum in figure 6 and the position of the line are reproduced within the errors as it is shown in figure 6. The detection of the line in the  $400$ - $600$  keV band is estimated at the  $16\sigma$  level.

#### 4. CONCLUSIONS

We simulated an *IBIS*/*INTEGRAL* observation of a bright X-ray Nova of a flare containing an enlarged gaussian ( $\sigma=22$  keV)  $\gamma$ -ray line at  $480$  keV from a bright X-ray Nova. Our preliminary results concerning the *IBIS* imager show that the line should be clearly detected by the *PiCsIT* layer and also in *Compton*-selected photons. We obtain  $\sim 10^5$  *ISGRI* events,  $\sim 7 \times 10^4$  *PiCsIT* events and about  $3.4 \times 10^3$  *Compton* events from the X-ray Nova. The source is clearly detected in both of the instrument layers and in the *Compton* mode. The complete energy coverage goes up to  $600$  keV.

The absence at the present stage of a response matrix did not allow us to deconvolve the simulated spectrum. However the  $\sim 500$  keV feature is clearly detected at thus confirming the expectations on *IBIS* contribution on this particular topic. It is expected that this observations will provide crucial information on the accretion processes taking place in X-ray

Novae.

#### REFERENCES

- Brun R. et al. 1994, CERN Program Library Long Writeup W5013, 1994
- Cannizzo J. 1993 in "Accretion Discs in Compact Stellar Systems" Ed. J.C. Wheeler, World Scientific Singapore pag. 6
- Chen W. et al., 1997 ApJ 491, 312
- Elvis M. et al., 1975, Nature 257, 656
- Gierlinski M. et al., 1999, MNRAS 309, 496
- Goldoni P., 1999, Proceedings of Vulcano workshop Eds. F. Giovannelli, G. Mannocchi, SIF Bologna
- Goldwurm A. 1992, ApJ 389, L79
- Laurent P. & Titarchuk L. 1999, ApJ 511, 289
- Laurent P. et al. 2000, these Proceedings
- Martin E.L. 1996, New Astronomy I, 197
- Paciesas W.S. et al. 1995 in "The  $\gamma$ -ray sky as seen with *Compton GRO* and *SIGMA*" M. Signore, P. Salati, G. Vedrenne eds., Kluwer Academic Publisher, The Netherlands.
- Sunyaev R. & Titarchuk L. 1980, A& A 86, 121
- Sunyaev R. et al. 1992, ApJ 389, L75
- Tanaka Y. & Shibazaki N., 1996, ARAA 34, 607